US007705547B2

(12) United States Patent
Schindel et al.

(10) **Patent No.:** **US 7,705,547 B2**

(45) **Date of Patent:** **Apr. 27, 2010**

(54) **HIGH-SIDE CURRENT SENSE HYSTERETIC LED CONTROLLER**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 215 days.

(21) Appl. No.: **11/551,167**

(22) Filed: **Oct. 19, 2006**

(65) **Prior Publication Data**

US 2008/0106217 A1 May 8, 2008

(51) **Int. Cl.**
G05F 1/00 (2006.01)

(52) **U.S. Cl.** .... **315/307**; 315/291; 315/185 S; 315/247; 315/312

(58) **Field of Classification Search** .... 315/291, 315/307–311, 224, 225, 247, 312–326, 200 A, 315/185 S
See application file for complete search history.

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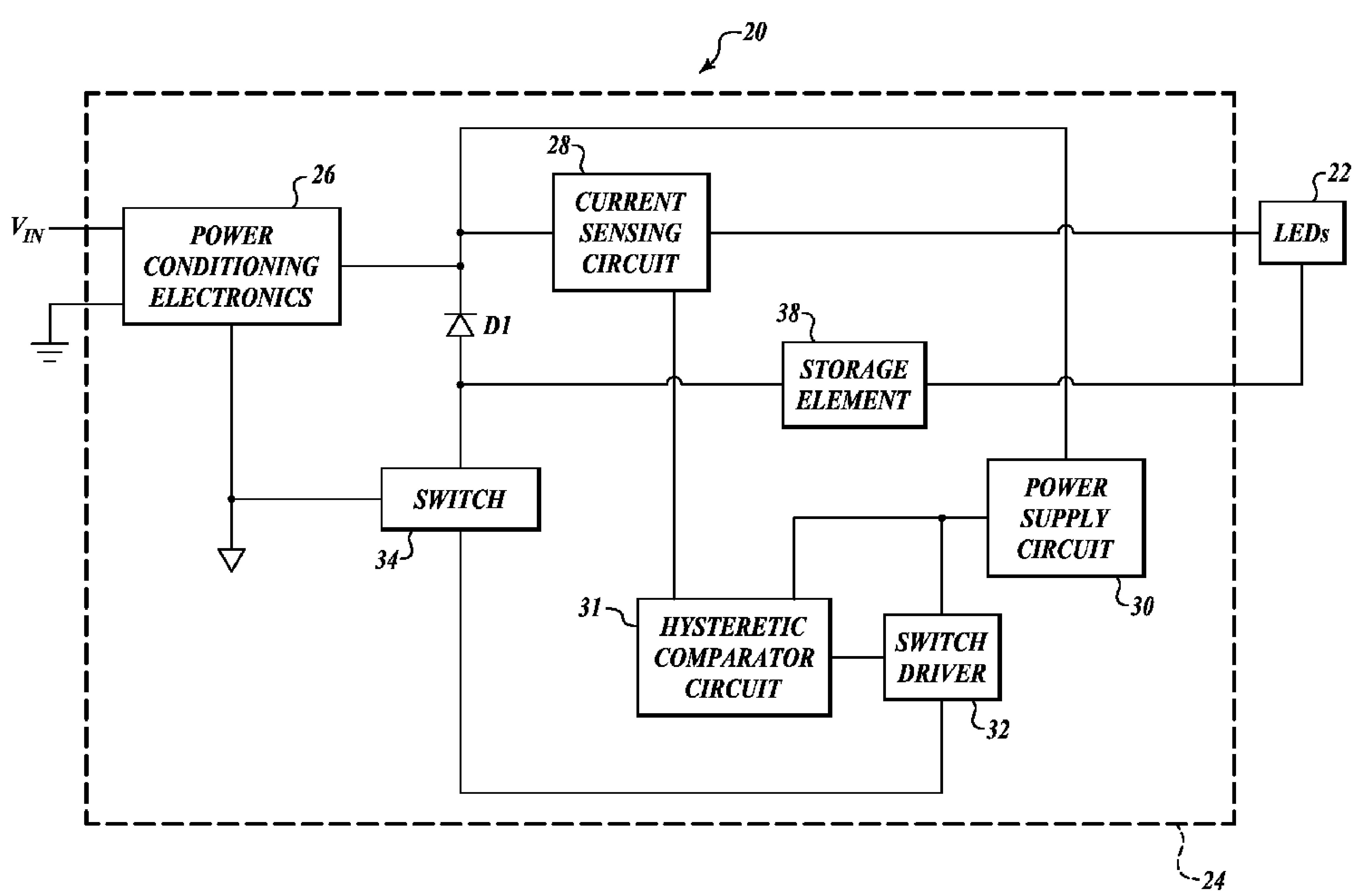
(57) **ABSTRACT**

Systems and methods for hysteretically controlling Light Emitting Diodes (LEDs) when the input voltage is greater than or equal to 18 volts. An example system includes one or more LEDs and a circuit electrically coupled to the one or more LEDs. The circuit hysteretically controls an input voltage supplied to the one or more LEDs based on a sensed electric current that passes through the LEDs. The circuit includes a MOSFET switch for switching on and off the input voltage supplied to the one or more LEDs, a current sensing subcircuit including a first integrated circuit (IC) for sensing the current flowing through the one or more LEDs, a hysteretic comparator circuit including a second IC for generating a hysteretic control signal based on the sensed current, and a switch driver including a third IC for controlling operation of the switch based on the generated hysteretic control signal.

14 Claims, 7 Drawing Sheets



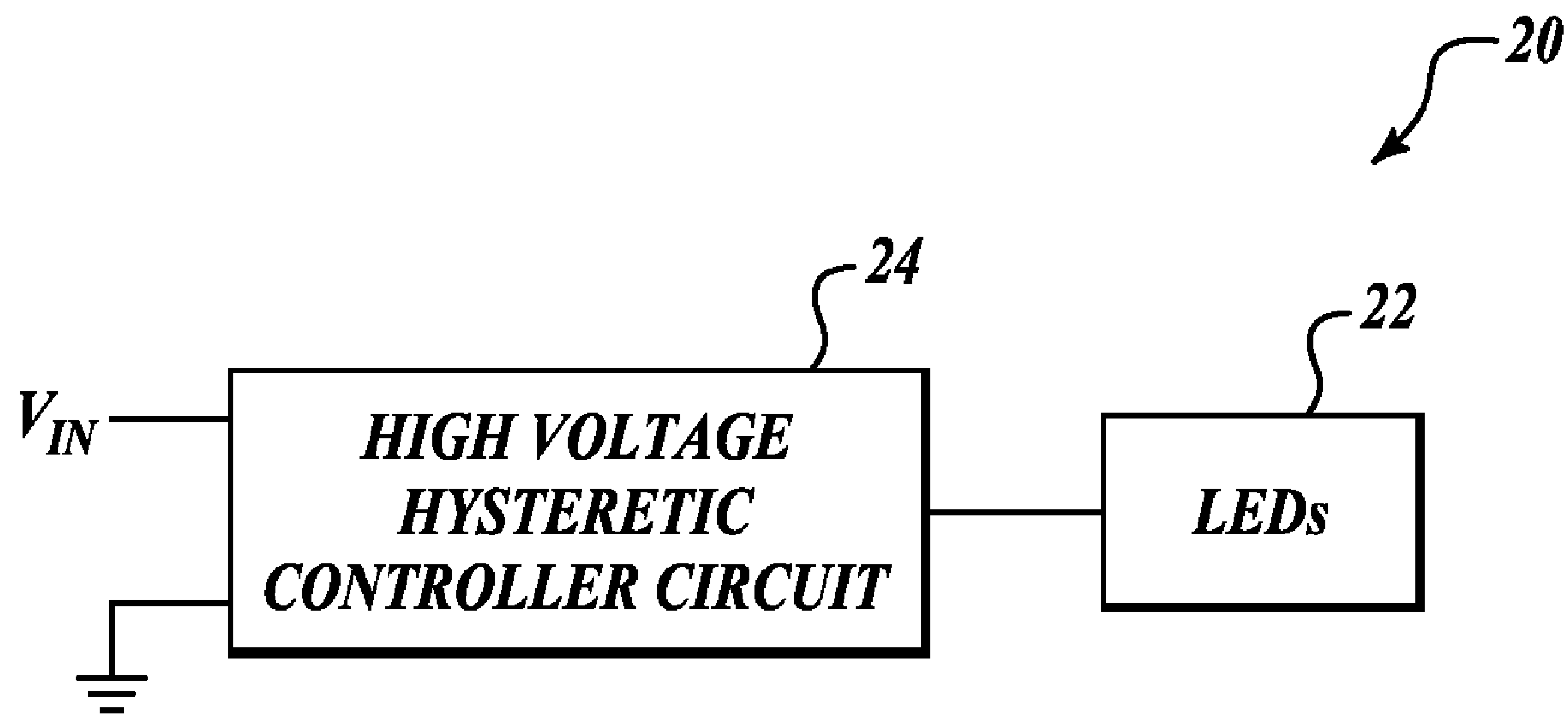

20
24
22
V_{IN}
HIGH VOLTAGE
HYSTERETIC
CONTROLLER CIRCUIT
LEDs

FIG.1

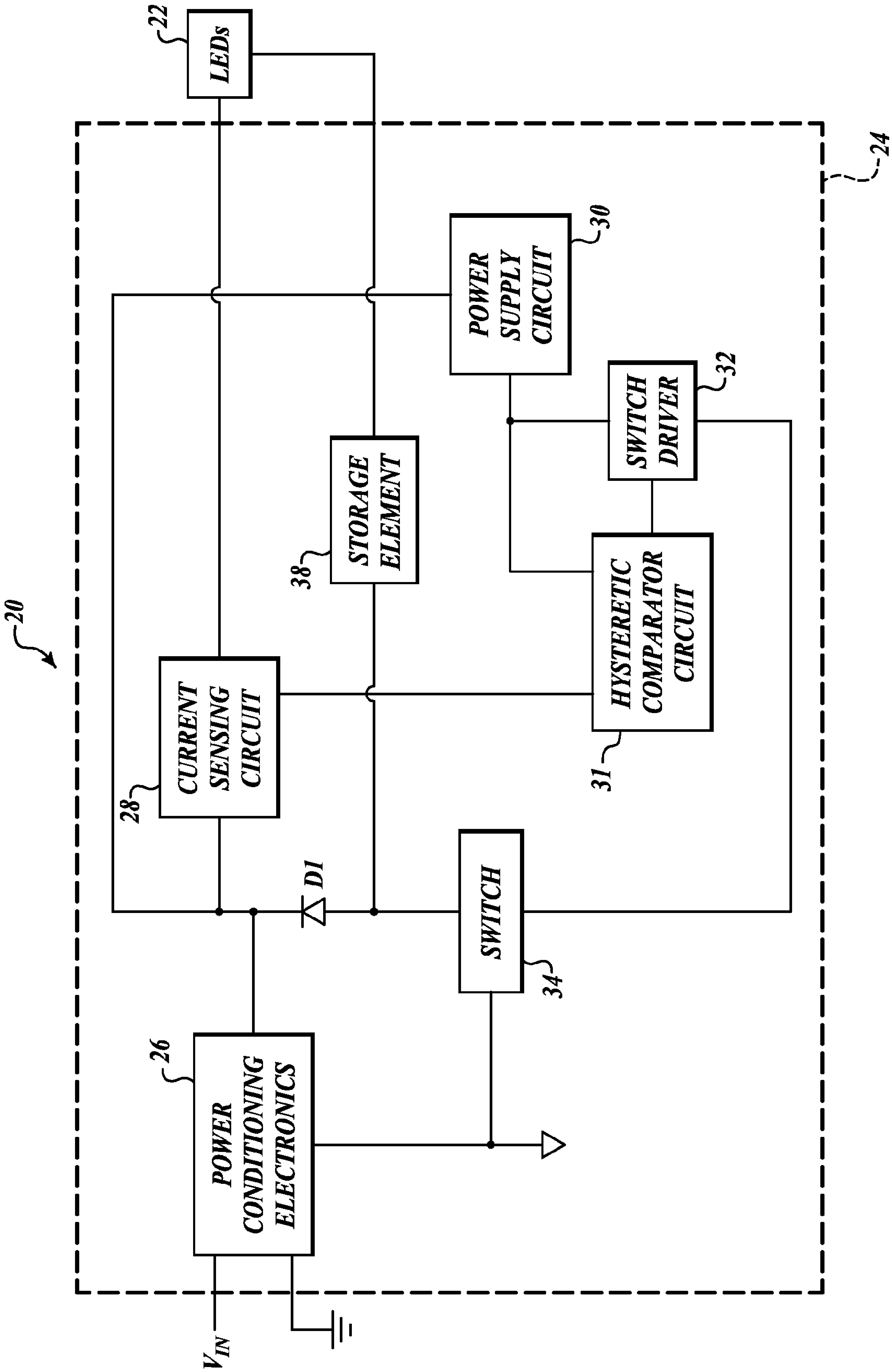
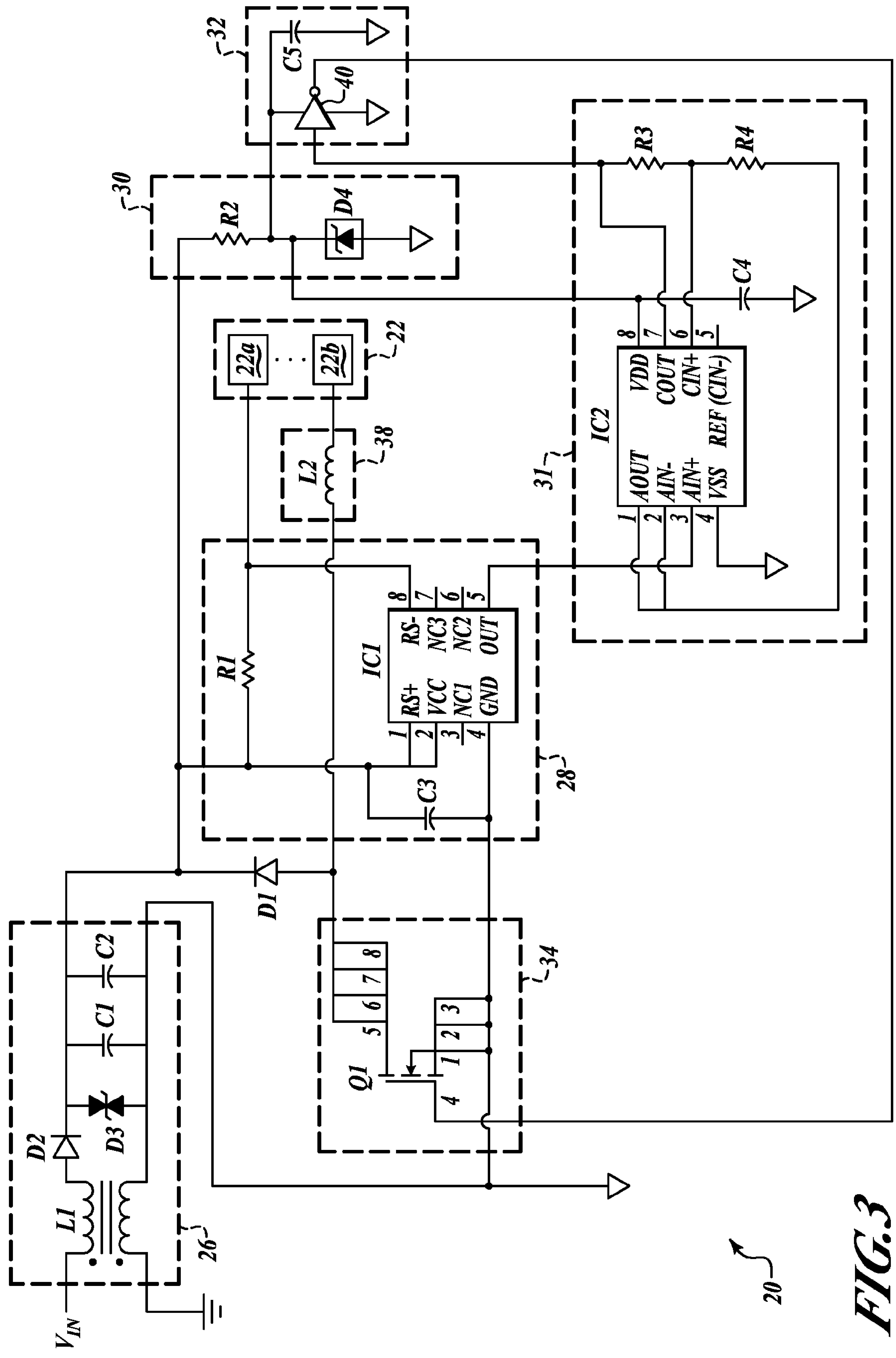

20
22
LEDs
24
POWER SUPPLY CIRCUIT
30
SWITCH DRIVER
32
STORAGE ELEMENT
38
HYSTERETIC COMPARATOR CIRCUIT
31
CURRENT SENSING CIRCUIT
28
D1
SWITCH
34
POWER CONDITIONING ELECTRONICS
26
V_{IN}

FIG.2



32
C5
40
30
R2
D4
R3
R4
C4
22
22a
22b
38
L2
31
IC2
VDD
COUT
CIN+
REF (CIN-)
AOUT
AIN-
AIN+
VSS
R1
IC1
RS+
VCC
NC1
GND
RS-
NC3
NC2
OUT
28
C3
D1
C1
C2
D2
D3
L1
26
V_{IN}
Q1
34
20

FIG.3

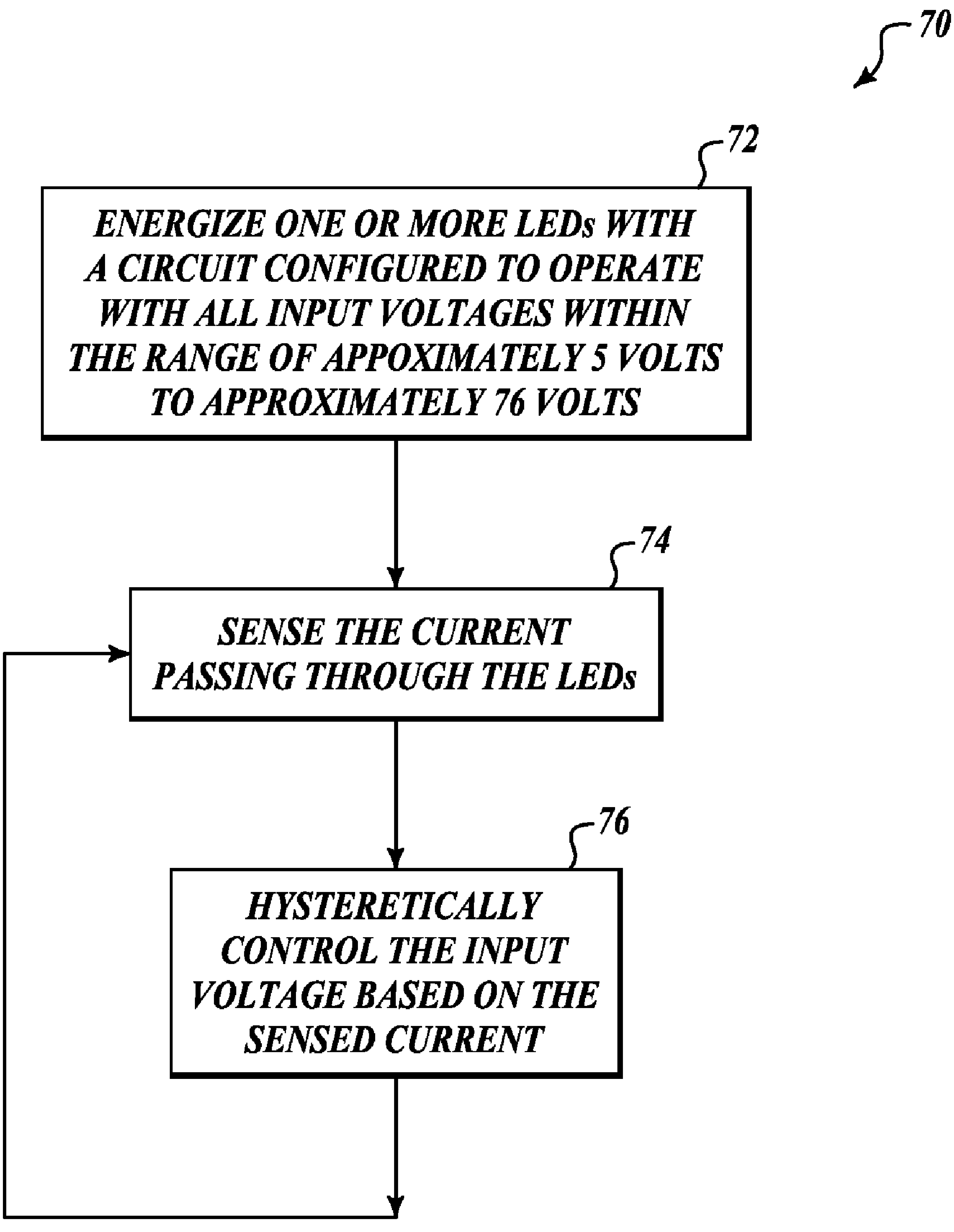

70
72
ENERGIZE ONE OR MORE LEDs WITH A CIRCUIT CONFIGURED TO OPERATE WITH ALL INPUT VOLTAGES WITHIN THE RANGE OF APPOXIMATELY 5 VOLTS TO APPROXIMATELY 76 VOLTS
74
SENSE THE CURRENT PASSING THROUGH THE LEDs
76
HYSTERETICALLY CONTROL THE INPUT VOLTAGE BASED ON THE SENSED CURRENT

FIG. 4

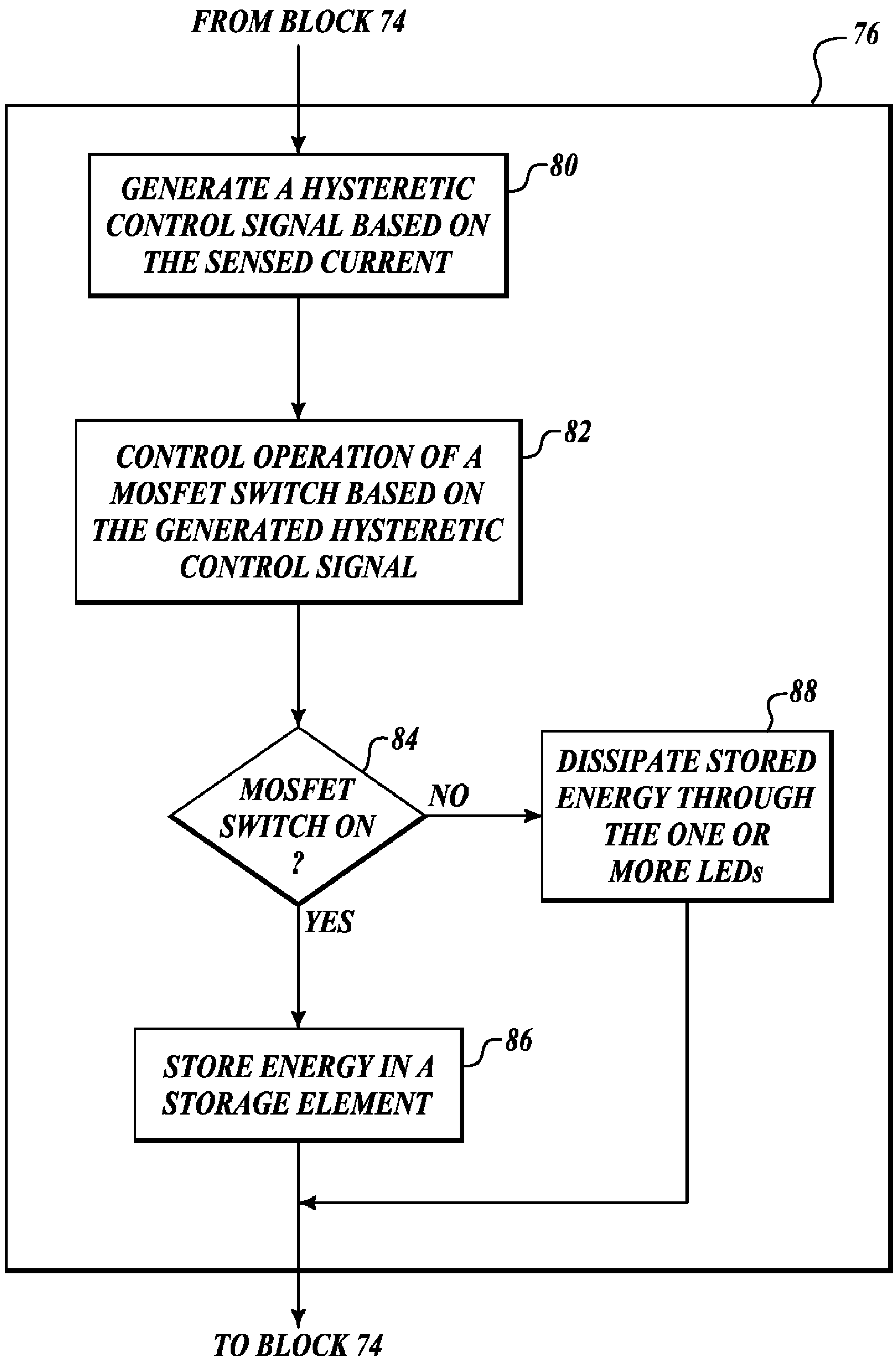

FROM BLOCK 74
76
GENERATE A HYSTERETIC CONTROL SIGNAL BASED ON THE SENSED CURRENT
80
CONTROL OPERATION OF A MOSFET SWITCH BASED ON THE GENERATED HYSTERETIC CONTROL SIGNAL
82
MOSFET SWITCH ON ?
84
NO
YES
DISSIPATE STORED ENERGY THROUGH THE ONE OR MORE LEDs
88
STORE ENERGY IN A STORAGE ELEMENT
86
TO BLOCK 74

FIG. 5

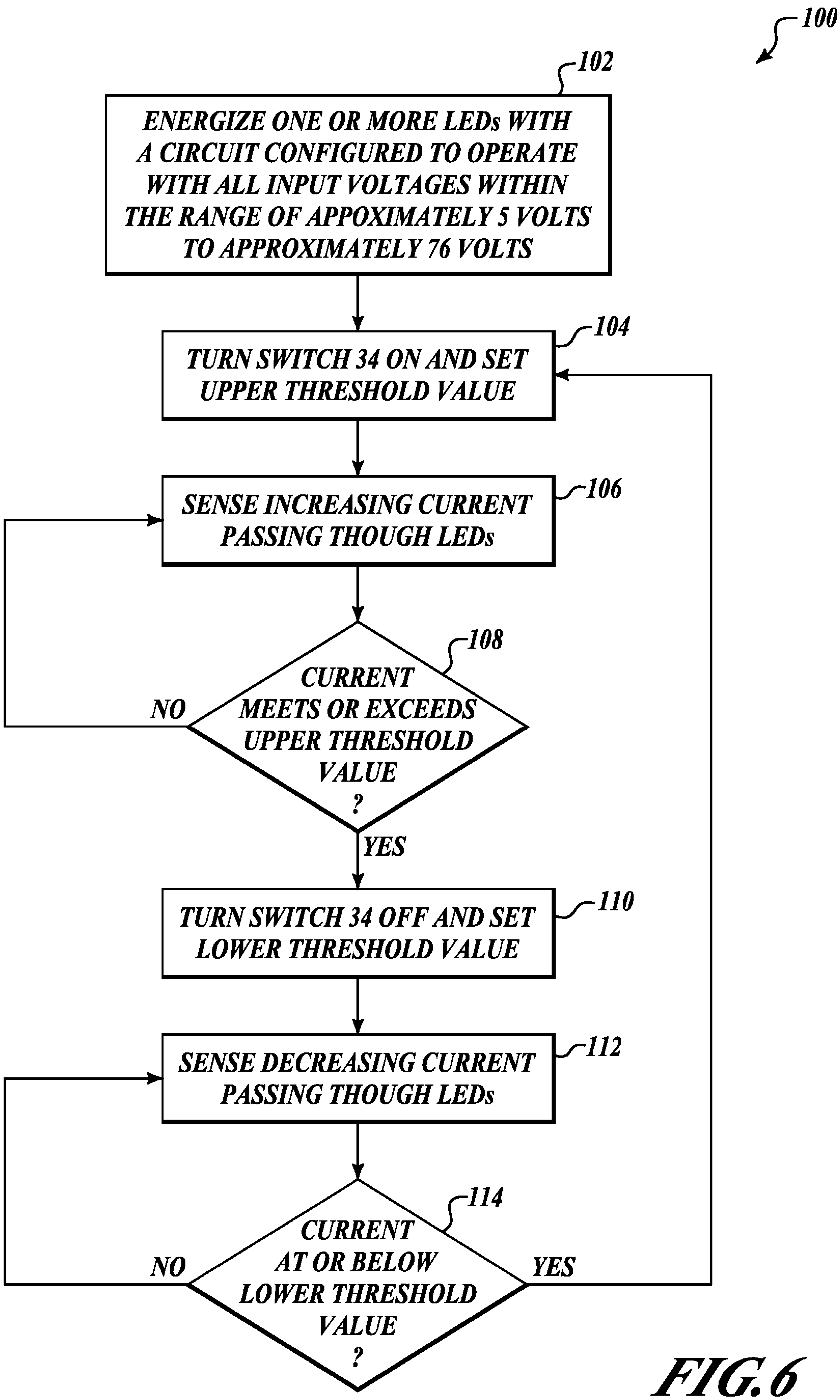

100
102
ENERGIZE ONE OR MORE LEDs WITH A CIRCUIT CONFIGURED TO OPERATE WITH ALL INPUT VOLTAGES WITHIN THE RANGE OF APPOXIMATELY 5 VOLTS TO APPROXIMATELY 76 VOLTS
104
TURN SWITCH 34 ON AND SET UPPER THRESHOLD VALUE
106
SENSE INCREASING CURRENT PASSING THOUGH LEDs
108
CURRENT MEETS OR EXCEEDS UPPER THRESHOLD VALUE ?
NO
YES
110
TURN SWITCH 34 OFF AND SET LOWER THRESHOLD VALUE
112
SENSE DECREASING CURRENT PASSING THOUGH LEDs
114
CURRENT AT OR BELOW LOWER THRESHOLD VALUE ?
NO
YES

FIG. 6

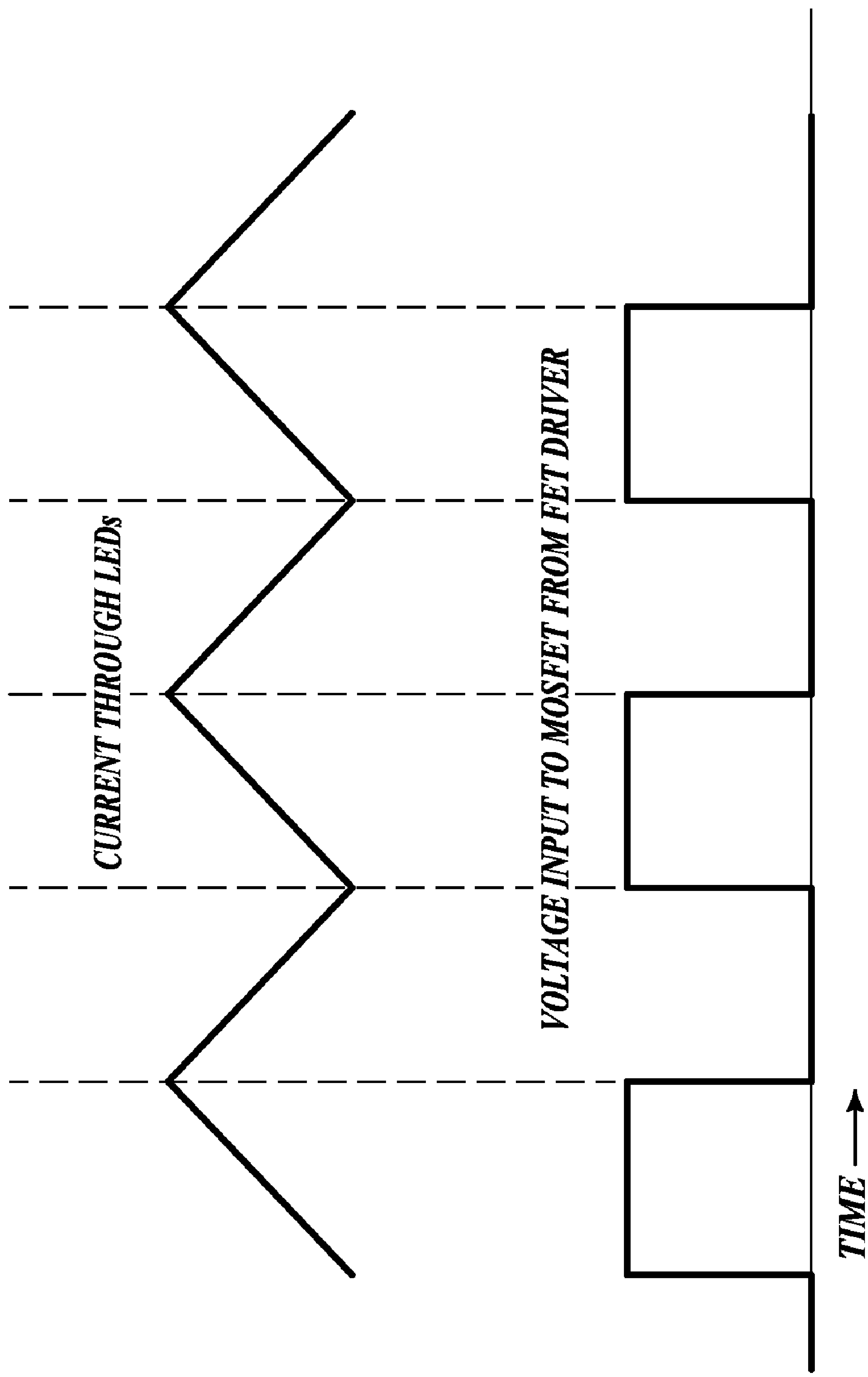

CURRENT THROUGH LEDs
VOLTAGE INPUT TO MOSFET FROM FET DRIVER
TIME

FIG. 7

HIGH-SIDE CURRENT SENSE HYSTERETIC LED CONTROLLER

BACKGROUND OF THE INVENTION

Current hysteretic controllers for Light Emitting Diodes (LEDs) are either limited to an input voltage below 18 volts or use complex implementations involving level shifting and charge pumps implemented with discrete electronic components to control a high-side switch. Other high voltage LED controllers require large inductor values or sense the current only when the switch is on. This leads to errors in the average value of the current being controlled. Therefore, a need exists for a hysteretic controller with a simple, less costly, implementation that allows for an input voltage greater than or equal to 18 volts.

SUMMARY OF THE INVENTION

The present invention provides systems and methods for hysteretically controlling Light Emitting Diodes (LEDs) when the input voltage is greater than or equal to 18 volts. An example system includes one or more LEDs and a circuit electrically coupled to the one or more LEDs. The circuit hysteretically controls an input voltage supplied to the one or more LEDs based on a sensed electric current that passes through the LEDs.

In one aspect of the invention, the circuit includes a MOSFET switch for switching on and off the input voltage supplied to the one or more LEDs, a current sensing subcircuit for sensing the current flowing through the one or more LEDs, a hysteretic comparator circuit for generating a hysteretic control signal based on the sensed current, and a switch driver for controlling operation of the switch based on the generated hysteretic control signal.

In an additional aspect of the invention, the current sensing subcircuit includes a first integrated circuit (IC), the hysteretic comparator circuit includes a second IC, and the switch driver includes a third IC, resulting in a simple hysteretic controller implementation that accepts input voltages within the range starting at approximately 5 volts up to input voltages greater than 18 volts, such as up to at least approximately 76 volts.

BRIEF DESCRIPTION OF THE DRAWINGS

Preferred and alternative embodiments of the present invention are described in detail below with reference to the following drawings:

FIG. **1** illustrates an LED controller circuit formed in accordance with an embodiment of the present invention;

FIG. **2** illustrates additional detail for an example embodiment of the LED controller circuit shown in FIG. **1**;

FIG. **3** is a schematic diagram of an example embodiment of the LED controller circuit shown in FIG. **2**; and

FIGS. **4** and **5** are flowcharts of a method of controlling one or more LEDs in accordance with an embodiment of the invention.

FIG. **6** is a flowchart of a method describing the functionality of the circuit shown in FIGS. **2** and **3**.

FIG. **7** is an example timing diagram for the circuit shown in FIGS. **2-3** and processes shown in FIGS. **4-6**.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

FIG. **1** illustrates a Light Emitting Diode (LED) system **20**. The system **20** includes one or more LEDs **22** that are con-

trolled by a high voltage hysteretic controller circuit **24**. The high voltage hysteretic controller circuit **24** receives an input voltage (V_{IN}) that is greater than the voltage provided to the LEDs. Examples of voltage sources for the input voltage include a battery, car alternator, aircraft generator, or a lab power supply. The high voltage hysteretic controller circuit **24** is capable of receiving a V_{IN} greater than or equal to 5 volts up to a V_{IN} of approximately 76 volts with surges to approximately 80 volts and an external ground or return line as inputs and supplying a current that drives the LEDs **22**. Generally, the high voltage hysteretic controller circuit **24** provides a relatively constant average current to the LEDs **22** by monitoring the current supplied to the LEDs **22** and hysteretically controlling a switch connected to V_{IN} such that the current remains within a particular range.

FIG. **2** is a block diagram illustrating additional detail for an example embodiment of the LED system **20** shown in FIG. **1**. In this example embodiment, the high voltage hysteretic controller circuit **24** is shown to include a power conditioning circuit **26** that receives V_{IN} as an input and produces a cleaner voltage at an output to be used by other portions of the hysteretic controller circuit **24**. The power conditioning circuit **26** reduces radio frequency (RF) noise generated by the hysteretic controller and line voltage spikes in an example embodiment. The output of the power conditioning circuit **26** is connected to a current sensing circuit **28**, a power supply circuit **30**, and the cathode end of a free-wheeling diode D**1**. The power supply circuit **30** is used to power a hysteretic comparator circuit **31** and a switch driver **32**. The current sensing circuit **28** senses current that passes through the LEDs **22** and produces a voltage output, proportional to the sensed current, which is used as an input by the hysteretic comparator circuit **31**. The hysteretic comparator circuit **31** produces an output value that causes the switch driver **32** to turn a switch **34** on and off. When the switch **34** is on, current flows from the power conditioning circuit **26** through the current sensing circuit **28** to power the LEDs **22**. The current then passes through a storage element **38** that stores energy to be used when the switch **34** is off. The current then passes through the switch **34** to circuit return. When the current as sensed by the current sensing circuit **28** exceeds a specified threshold as determined by the hysteretic comparator circuit **31**, the output value changes causing the switch driver **32** to turn the switch **34** off. When the switch **34** is off, energy stored in the storage element **38** causes a current to flow through the diode D**1** and the current sensing circuit **28** before powering the LEDs **22**. When the current drops below a specified threshold as sensed by the current sensing circuit **28**, the output value produced by the hysteretic comparator circuit **31** changes, thus triggering the switch driver **32** which causes the switch **34** to turn back on.

FIG. **3** is a schematic diagram of detailed circuitry for an example embodiment of the LED controller circuit shown in FIG. **2**. Only a first LED **22***a* and a last LED **22***b* are shown from the one or more LEDs **22** for clarity. The power conditioning circuit **26** takes V_{IN} and an external ground or return line as inputs. This allows the power conditioning circuit **26** to be connected to a power bus in some embodiments, for example. The V_{IN} and external ground inputs are connected to a common mode choke L**1** to reduce electromagnetic interference (EMI). The high side of the choke L**1** output is connected to a diode's D**2** anode. The low side output of the choke L**1** is connected to circuit return. A bidirectional breakdown diode D**3**, a first capacitor C**1**, and a second capacitor C**2** are connected in parallel between the cathode of the diode D**2** and the low side output of the choke L**1**. The diode D**3**, first capacitor C**1**, and second capacitor C**2** assist in stabilizing V_{IN} to provide a good voltage source to be used by other components of the high voltage hysteretic controller circuit **24**.

The current sensing circuit **28** includes a current sense resistor R**1** and a first integrated circuit IC**1** that is used to sense the current flowing through the current sense resistor R**1**. In this example embodiment, the first integrated circuit IC**1** is a MAX4080 High Side, Current-Sense Amplifier with Voltage Output, produced by Maxim Integrated Products. However, ICs with similar characteristics could be used in other embodiments. Although the MAX4080 IC is rated to 76 Volts with a surge rating of 80 Volts, higher input voltages may be possible in other embodiments if the IC used is rated to accept them. The RS+, RS−, VCC, GND, and OUT pins of the MAX4080 chip are used. The RS+ and RS− pins are connected to the end of the sense resistor R**1** connected to the power conditioning circuit output and the first LED **22***a* anode, respectively. The VCC pin is connected to the power conditioning circuit output, the GND pin is connected to circuit return, and the OUT pin is connected to the hysteretic comparator circuit **31**. A third capacitor C**3** is electrically connected at one end to both the RS+ and VCC pins and at the other end to the GND pin.

The power supply circuit **30** includes a resistor R**2** connected at one end to the output of the power conditioning circuit **26** and at the other end to the cathode end of a unidirectional Zener breakdown diode D**4**, the anode of the diode D**4** being connected to circuit return. The hysteretic comparator circuit **31** includes an integrated circuit IC**2** that is powered by the voltage established by the breakdown diode D**4**. In this example embodiment, the integrated circuit IC**2** is a MAX9003 Low-Power, High-Speed, Single-Supply Op Amp+Comparator+Reference IC, produced by Maxim Integrated Products. However, ICs with similar characteristics could be used in other embodiments. The AOUT, AIN−, AIN+, VSS, VDD, COUT, and CIN+ pins of the MAX9003 chip are used. The VDD pin is connected to the cathode end of the breakdown diode D**4**, the VSS pin is connected to circuit return, and a fourth capacitor C**4** is connected between the VDD pin and circuit return. The AIN+ pin is connected to the OUT pin from the MAX4080 chip used as IC**1**. A third resistor R**3** is connected between the COUT and CIN+ pins. A fourth resistor R**4** is connected between the CIN+ pin and both the AOUT and AIN− pins. The COUT pin is also connected to the switch driver **32**. The third resistor R**3** and the fourth resistor R**4** are selected to achieve desired on and off points for hysteretic control.

The switch driver **32** is shown to include a MOSFET driver **40** and a fifth capacitor C**5**. The MOSFET driver **40** includes a power input that is connected to the cathode of the breakdown diode D**4**, a ground input that is connected to circuit return, a control input that is connected to the COUT pin from the MAX9003 chip used as IC**2**, and a gate output that is connected to the switch **34**. The fifth capacitor C**5** is connected between the power input of the MOSFET driver **40** and circuit return. As an example, the MOSFET driver **40** may be a MIC4417 IttyBittty™ Low-Side MOSFET Driver, produced by Micrel, Inc. The MIC4417 driver is an inverting driver that uses a TTL-compatible logic signal as an input. However, other drivers may be used in other embodiments. The MOSFET driver **40** is used to drive the switch **34**, which is shown in this embodiment as an N-channel MOSFET transistor Q**1** whose gate is driven by the gate output of the MOSFET driver **40**, source is connected to circuit return, and drain is connected to one end of the storage element **38**. In this embodiment, the storage element **38** is an inductor L**2** whose other end is connected to the cathode of the last LED **22***b* in the one or more LEDs **22**.

When V_{IN} is applied, the high voltage hysteretic controller circuit **24** powers up in a state such that the output of the hysteretic comparator circuit **31** is low. This places the MOSFET transistor Q**1** in its ‘ON’ state using the switch driver **32**. The current in the inductor L**2** begins to ramp up and the LEDs **22** illuminate as the current is passing through them. The high-side current sensing circuit **28** amplifies the voltage developed across the sense resistor R**1** to provide an amplified sense signal output voltage that is proportional to the voltage developed across the sense resistor R**1**. The amplified sense signal output voltage is fed to the hysteretic comparator circuit **31**. When the amplified sense signal output voltage equals the threshold value of the hysteretic comparator circuit **31**, the output of the hysteretic comparator circuit **31** transitions from low to high, establishing a new threshold value. The high on the output of the hysteretic comparator circuit **31** turns the MOSFET transistor Q**1** ‘OFF’ using the switch driver **32**. This causes the current in the inductor L**2** and the LEDs **22** to recirculate through the free-wheeling diode D**1**. As the current ramps down, the high side current sensing circuit **28** continues to provide a signal that is proportional to the current in the LEDs **22**. When the amplified signal equals the lower threshold value of the hysteretic comparator circuit **31**, the output of the hysteretic comparator circuit **31** transitions from high to low, turning the MOSFET transistor Q**1** back ‘ON’ using the switch driver **32** and reestablishing the high threshold value. The cycle then repeats.

FIGS. **4** and **5** are flowcharts of a method **70** of controlling one or more LEDs in accordance with an embodiment of the invention. FIG. **4** shows that the method **70** begins at a block **72** where one or more LEDs are energized with a circuit configured to operate with all input voltages within the range of approximately 5 volts to approximately 76 volts. Next, at a block **74**, the current passing through the LEDs is sensed. Then, at a block **76**, the input voltage is hysteretically controlled based on the sensed current. The method **70** then loops back to the block **74** where the current passing through the LEDs is sensed again. In an example embodiment illustrated in FIG. **5**, the block **76** is shown to include a number of other blocks that describe in greater detail an example method of hysteretically controlling the input voltage based on the sensed current. First, at a block **80**, a hysteretic control signal is generated based on the sensed current. Next, at a block **82**, a MOSFET switch is controlled based on the generated hysteretic control signal. Then, at a decision block **84**, it is determined whether the MOSFET switch is on. If the MOSFET switch is on, energy is stored in a storage element at a block **86** and the LEDs are powered by the input voltage. Then, the method loops back to the block **74**. If the MOSFET switch is off, the stored energy in the storage element is dissipated through the one or more LEDs at a block **88**. Then, the method loops back to the block **74**.

FIG. **6** is a flowchart of a method **100** describing the functionality of the circuit **20** shown in FIGS. **2** and **3**. First, at a block **102**, one or more LEDs are energized with a circuit configured to operate with all input voltages within the range of approximately 5 volts to approximately 76 volts. Next, at a block **104**, the switch **34** is turned on and an upper threshold value for the hysteretic comparator circuit **31** is set. Then, at a block **106**, increasing current passing through the LEDs **22** is sensed with the current sensing circuit **28**. Then, at a decision block **108**, it is determined whether the sensed current meets or exceeds the upper threshold value. If the sensed current does not meet or exceed the upper threshold value, the method **100** loops back to the block **106**. If the sensed current does meet or exceed the upper threshold value, the method proceeds to a block **110** where the switch **34** is turned off and the lower threshold value is set. Then, at a block **112**, decreasing current is sensed passing through the LEDs **22** with the current sensing circuit **28**. Next, at a decision block **114**, it is determined whether the sensed current is at or below the lower threshold value. If the sensed current is not at or below the threshold value, the method loops back to the block **112**. If the sensed current is at or below the threshold value, the method loops back to the block **104** where the switch **34** is turned on again and the upper threshold value is set. The method **100** then proceeds as described above.

FIG. **7** is an example timing diagram for the circuit shown in FIGS. **2-3** and processes shown in FIGS. **4-6**.

While the preferred embodiment of the invention has been illustrated and described, as noted above, many changes can be made without departing from the spirit and scope of the invention. For example, changes could be made to the power conditioning circuit such as combining the first capacitor C**1** and the second capacitor C**2**, or the power conditioning circuit could be eliminated if a clean and stable voltage source was available as an input. Additionally, different types of ICs that perform similar functions to the example ICs mentioned could be used. Further, a non-inverting switch driver rather than an inverting switch driver **32** could be used if the hysteretic comparator circuit **31** output was also changed. Additionally, a V_{IN} lower than 18 V could be used depending on how many LEDs were being driven. Accordingly, the scope of the invention is not limited by the disclosure of the preferred embodiment. Instead, the invention should be determined entirely by reference to the claims that follow.

The embodiments of the invention in which an exclusive property or privilege is claimed are defined as follows:

1. A Light Emitting Diode (LED) system comprising:

one or more LEDs; and

a circuit electrically coupled to the one or more LEDs for hysteretically controlling an input voltage supplied to the one or more LEDs,

wherein the circuit is configured to operate with all input voltages within a range of approximately 5 volts to approximately 76 volts,

wherein the circuit comprises:

a switch for switching on and off the input voltage supplied to the one or more LEDs;

a current sensing subcircuit for sensing the current flowing through the one or more LEDs;

a hysteretic comparator subcircuit for generating a hysteretic control signal based on the sensed current; and

a switch driver for controlling operation of the switch based on the generated hysteretic control signal, and

wherein the current sensing subcircuit senses current on a high side of the one or more LEDs.

2. The system of claim **1**, wherein the circuit is configured to operate with input surge voltages up to approximately 80 volts.

3. The system of claim **1**, wherein the switch includes a MOSFET switch.

4. The LED system of claim **1**, wherein the circuit is electrically coupled to a plurality of LEDs for hysteretically controlling an input voltage supplied to the plurality of LEDs.

5. The system of claim **1**, wherein the circuit further comprises a storage element configured to store energy when the switch is turned on and the stored energy is dissipated to the one or more LEDs when the switch is turned off.

6. The system of claim **5**, wherein the storage element includes an inductor connected in series with the one or more LEDs.

7. A method for controlling a current through one or more Light Emitting Diodes (LEDs), the method comprising:

sensing current passing though the LEDs; and

hysterically controlling an input voltage used to power the one or more LEDs based on the sensed current,

wherein the input voltage is within a range of approximately 5 volts to approximately 76 volts, and wherein sensing current occurs on a high side of the LEDs.

8. The method of claim **7**, wherein the input voltage is between approximately 18 volts and approximately 76 volts.

9. The method of claim **7**, wherein the input voltage contains voltage surges of up to approximately 80 volts.

10. The method of claim **7**, wherein sensing current includes sensing current passing through a plurality of LEDs.

11. The method of claim **7**, wherein hysteretically controlling comprises:

generating a hysteretic control signal based on the sensed current; and

controlling operation of a MOSFET switch based on the generated hysteretic control signal.

12. The method of claim **11**, further comprising:

storing energy in a storage element when the MOSFET switch is turned on; and

dissipating the stored energy through the one or more LEDs when the MOSFET switch is turned off.

13. The method of claim **12**, wherein controlling comprises:

receiving the generated hysteretic control signal at a switch driver; and

driving the MOSFET switch based on the received hysteretic control signal.

14. A Light Emitting Diode (LED) system comprising:

one or more LEDs; and

a circuit electrically coupled to the one or more LEDs for hysteretically controlling an input voltage supplied to the one or more LEDs,

wherein the circuit is configured to operate with all input voltages within a range of approximately **5** volts to approximately 76 volts, wherein the circuit comprises:

a switch for switching on and off the input voltage supplied to the one or more LEDs;

a current sensing subcircuit for sensing the current flowing through the one or more LEDs;

a hysteretic comparator subcircuit for generating a hysteretic control signal based on the sensed current; and

a switch driver for controlling operation of the switch based on the generated hysteretic control signal,

wherein the current sensing subcircuit comprises:

a resistor connected in series with the one or more LEDs; and

a current sensing integrated circuit connected across the resistor, wherein an output of the current sensing integrated circuit is connected to an input of the hysteretic comparator subcircuit.

* * * * *